ARTICLE IN PRESS

Engineering Fracture Mechanics xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Engineering Fracture Mechanics

journal homepage: www.elsevier.com/locate/engfracmech

Experiences and recommendations for numerical analyses of notch stress intensity factor and averaged strain energy density

C. Fischer [a], W. Fricke [a], C.M. Rizzo [b,*]

[a] *Institute of Ship Structural Design and Analysis, Hamburg University of Technology, Hamburg, Germany*
[b] *Marine Structures Testing Lab, DITEN, University of Genova, Genova, Italy*

ARTICLE INFO

Article history:
Received 16 October 2015
Received in revised form 7 August 2016
Accepted 10 August 2016
Available online xxxx

Keywords:
Notch stress intensity factor
Averaged strain energy density
Finite element method
Welded joints
Benchmark study
Approximation error

ABSTRACT

This paper aims at providing recommendations for the practical application of relatively novel fatigue assessment approaches. Although the concept of notch stress intensity factor (N-SIF) itself was proposed decades ago to provide the analytical solution of the stress field in way of sharp notches, only recently it has been considered as the basis for fatigue strength assessment of welded joints. N-SIF itself and derived quantities such as the equivalent peak stress or the averaged strain energy density (SED) can be assumed as fatigue governing parameters and applied in everyday engineering practice being supported by powerful computation facilities. The N-SIF approach is still too cumbersome for practical applications; the SED approach seems promising to overcome shortcomings, to be applied flexibly to different joint geometries and possibly to automate the calculation procedure in finite element analysis. Software having different features and different refinement strategies are applied in order to benchmark advantages and disadvantages of possible practical solutions for the approaches based on N-SIF and averaged SED, thus offering various element types and modelling strategies. In general, high computational accuracy has been verified, despite relatively coarse meshes, if the element type, shape and mesh pattern is selected properly. However, the approach based on the averaged SED can be unsuitable for studying the notch effect of varying geometries if the averaging area increases more than the local stress concentration rises, as shown for the simplified geometry of a butt joint.

1. Introduction

Different methodologies and several corresponding approaches have been and are still being proposed in order to estimate the fatigue strength of welded joints, see e.g. Radaj et al. [39,40]. Fricke [17] has recently outlined the latest developments and future challenges in fatigue strength estimation, pointing out links among different approaches. In local approaches, the weld toe and the weld root are often idealized as geometrical notches with different opening angles and notch radii to account directly for the local weld geometry and the local stress concentration, both significantly influencing the fatigue strength.

If the well-known effective notch stress approach is applied [21,15], the weld toe and weld root of structural steel welded joints are rounded by a fictitious radius of 1 mm to account for the micro-structural support effect of the surrounding mate-

* Corresponding author.
E-mail address: cesare.rizzo@unige.it (C.M. Rizzo).

http://dx.doi.org/10.1016/j.engfracmech.2016.08.012
0013-7944/© 2016 Elsevier Ltd. All rights reserved.

Nomenclature

$\frac{dU}{dV}$	strain energy density (energy per infinitesimal volume)
E, ν	Young modulus and Poisson coefficient of (elastic isotropic) material
e_1, e_2	integral coefficients depending on the notch opening angle
e_E	relative error determined in energy norm
K_1, K_2	mode 1, mode 2 notch stress intensity factor
n_E	number of finite elements in the control volume
R_c	radius of cylindrical control volume
R^*	radius of increased control volume
r_n	radial distance from the notch root
t	thickness
U_i	strain energy per finite element
V_i	finite element volume
$\overline{W}$	averaged strain energy density (SED)
$\overline{W}_{ref}$	reference value of averaged SED used in the convergence study
w, h	weld bead size
2α	notch opening angle
γ	angle between the notch surface and the bisecting line
λ_1, λ_2	eigenvalues of the Williams' solution of stress field at notches
ρ	notch tip radius
σ_n	nominal stress at far field
$\vec{\sigma}$, $\vec{\varepsilon}$	stress, strain tensors
σ_θ, σ_r, σ_z, $\tau_{r\theta}$	stress components in way of notch (cylindrical reference system)

rial, according to the well-known Neuber's hypothesis further elaborated by Radaj et al. [39]. The stress parameter assumed to govern the fatigue strength is computed commonly via finite element (FE) analysis adopting suitably refined meshes. This approach has been applied to an increasing extent in the last years. However, applications and predictions are not always in agreement among different users, see e.g. Fricke et al. [13,16], or with other approaches, e.g. Ringsberg et al. [45]. Additionally, the fictitious notch radius does not cover the fatigue parameter correctly for all possible notch opening angles [50]. Therefore, Radaj et al. [43] have recently generalised the approach, considering also differently shaped notches and loading conditions; see also Radaj and Vormwald [42], Chapter 1, for a comprehensive summary. Zhang et al. [50] compared three local approaches, based on the notch stress, showing how these take into account the effect of the opening angle. Their recently proposed fatigue parameter, the so-called effective stress, is considered independent of the opening angle since they

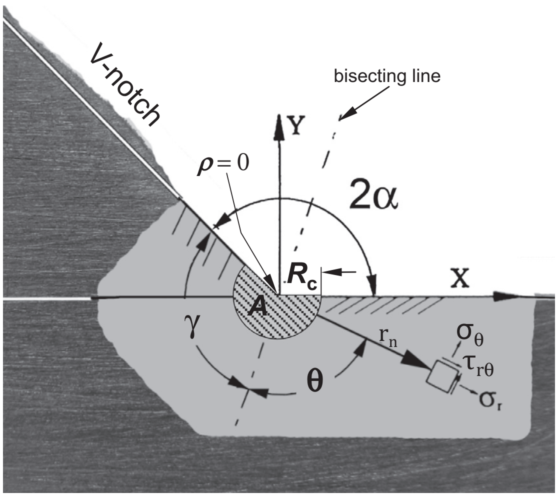

Fig. 1. Idealization of weld toe as a geometrical notch with opening angle $2\alpha = 135°$ and null notch radius ρ, control volume of radius R_c is also shown.

Please cite this article in press as: Fischer C et al. Experiences and recommendations for numerical analyses of notch stress intensity factor and averaged strain energy density. Engng Fract Mech (2016), http://dx.doi.org/10.1016/j.engfracmech.2016.08.012